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(54) **IMPLANTABLE ELECTRODE AND METHOD OF MAKING THE SAME**

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,847,687 A 11/1974 Davidsohn et al.

3,921,916 A 11/1975 Bassous

(Continued)

FOREIGN PATENT DOCUMENTS

WO 0112115 2/2001

WO 0236002 5/2002

(Continued)

OTHER PUBLICATIONS

Application No. PCT/1B06/53700, International Search Report
mailed Nov. 21, 2008.

(Continued)

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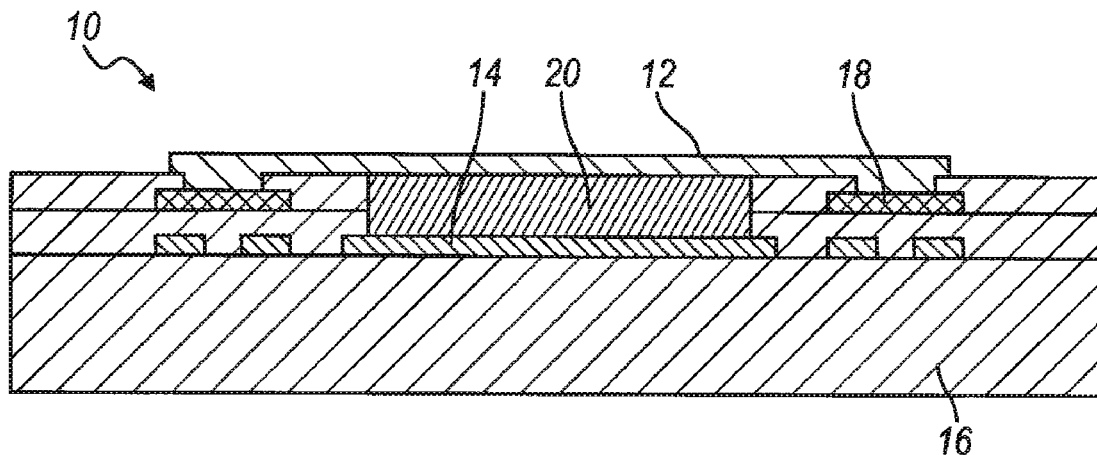
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(57) **ABSTRACT**

The implantable electrode system of the preferred embodiments includes a conductor, an interconnect coupled to the conductor, an insulator that insulates the interconnect, and an anchor that is connected to both the conductor and the insulating element. The anchor is mechanically interlocked with at least one of the conductor and the insulator.

29 Claims, 3 Drawing Sheets



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- (56) **References Cited**
- U.S. PATENT DOCUMENTS
- | | | | |
|--------------|------|---------|--------------------------------|
| 4,141,365 | A | 2/1979 | Fischell et al. |
| 4,166,469 | A | 9/1979 | Littleford |
| 4,306,562 | A | 12/1981 | Osborne |
| 4,455,192 | A | 6/1984 | Tamai |
| 4,461,304 | A | 7/1984 | Kuperstein |
| 4,465,482 | A | 8/1984 | Tittel |
| 4,762,135 | A | 8/1988 | van der Puije |
| 4,886,065 | A | 12/1989 | Collins, Jr. |
| 4,904,237 | A | 2/1990 | Janese |
| 5,108,819 | A | 4/1992 | Heller et al. |
| 5,180,376 | A | 1/1993 | Fischell |
| 5,207,709 | A | 5/1993 | Picha |
| 5,215,088 | A | 6/1993 | Normann et al. |
| 5,308,442 | A | 5/1994 | Taub et al. |
| 5,322,064 | A | 6/1994 | Lundquist |
| 5,385,635 | A | 1/1995 | O'Neill |
| 5,390,671 | A | 2/1995 | Lord et al. |
| 5,409,469 | A | 4/1995 | Schaerf |
| 5,496,360 | A | 3/1996 | Hoffmann et al. |
| 5,515,848 | A | 5/1996 | Corbett, III et al. |
| 5,524,338 | A | 6/1996 | Martyniuk et al. |
| 5,573,520 | A | 11/1996 | Schwartz et al. |
| 5,585,827 | A | 12/1996 | Murakami |
| 5,588,597 | A | 12/1996 | Reinecke et al. |
| 5,720,099 | A | 2/1998 | Parker et al. |
| 5,744,958 | A | 4/1998 | Werne |
| 5,800,535 | A | 9/1998 | Howard, III |
| 5,843,150 | A | 12/1998 | Dreessen et al. |
| 5,927,277 | A | 7/1999 | Baudino et al. |
| 5,938,694 | A | 8/1999 | Jaraczewski et al. |
| 5,975,085 | A | 11/1999 | Rise |
| 5,989,445 | A | 11/1999 | Wise et al. |
| 5,992,769 | A | 11/1999 | Wise et al. |
| 6,006,124 | A | 12/1999 | Fischell et al. |
| 6,016,449 | A | 1/2000 | Fischell et al. |
| 6,044,304 | A | 3/2000 | Baudino |
| 6,132,456 | A | 10/2000 | Sommer et al. |
| 6,181,569 | B1 | 1/2001 | Chakravorty |
| 6,205,361 | B1 | 3/2001 | Kuzma et al. |
| 6,228,111 | B1 | 5/2001 | Törmälä et al. |
| 6,324,433 | B1 | 11/2001 | Errico |
| 6,325,797 | B1 | 12/2001 | Stewart et al. |
| 6,374,143 | B1 | 4/2002 | Berrang et al. |
| 6,430,443 | B1 | 8/2002 | Karell |
| 6,600,231 | B2 | 7/2003 | Tominaga |
| 6,618,623 | B1 | 9/2003 | Pless et al. |
| 6,829,498 | B2 | 12/2004 | Kipke et al. |
| 6,834,200 | B2 | 12/2004 | Moxon et al. |
| 6,878,643 | B2 | 4/2005 | Krulevitch et al. |
| 7,004,948 | B1 | 2/2006 | Pianca et al. |
| 7,006,859 | B1 | 2/2006 | Osorio et al. |
| 7,010,356 | B2 | 3/2006 | Jog et al. |
| 7,011,680 | B2 | 3/2006 | Alt |
| 7,089,059 | B1 | 8/2006 | Pless |
| 7,181,288 | B1 | 2/2007 | Rezai et al. |
| 7,343,205 | B1 | 3/2008 | Pianca et al. |
| 7,548,775 | B2 | 6/2009 | Kipke et al. |
| 7,871,707 | B2 | 1/2011 | Laude et al. |
| 7,914,842 | B1 * | 3/2011 | Greenberg et al. 427/2.24 |
| 7,941,202 | B2 | 5/2011 | Hetke et al. |
| 8,120,229 | B2 | 2/2012 | Huang |
| 2001/0049499 | A1 | 12/2001 | Lui et al. |
| 2002/0052610 | A1 | 5/2002 | Skakoon et al. |
| 2002/0183817 | A1 | 12/2002 | Van Venrooij et al. |
| 2002/0198446 | A1 | 12/2002 | Hill et al. |
| 2003/0093129 | A1 | 5/2003 | Nicolelis et al. |
| 2003/0100823 | A1 | 5/2003 | Kipke et al. |
| 2003/0114906 | A1 | 6/2003 | Booker et al. |
| 2003/0187461 | A1 | 10/2003 | Chin |
| 2004/0006264 | A1 | 1/2004 | Mojarradi et al. |
| 2004/0102828 | A1 | 5/2004 | Lowry et al. |
| 2004/0106169 | A1 | 6/2004 | Evans |
| 2004/0199235 | A1 | 10/2004 | Younis |
| 2005/0004627 | A1 | 1/2005 | Gibson et al. |
| 2005/0021116 | A1 | 1/2005 | He et al. |
| 2005/0021117 | A1 | 1/2005 | He et al. |
| 2005/0137647 | A1 | 6/2005 | Wallace et al. |
| 2005/0222647 | A1 | 10/2005 | Wahlstrand et al. |
| 2006/0122677 | A1 | 6/2006 | Vardiman |
| 2006/0173263 | A1 | 8/2006 | He et al. |
| 2006/0247749 | A1 | 11/2006 | Colvin |
| 2006/0258951 | A1 | 11/2006 | Bleich et al. |
| 2006/0276866 | A1 | 12/2006 | McCreery |
| 2006/0282014 | A1 | 12/2006 | Kipke et al. |
| 2007/0073130 | A1 | 3/2007 | Finch et al. |
| 2007/0121305 | A1 * | 5/2007 | Iijima et al. 361/760 |
| 2007/0123765 | A1 | 5/2007 | Hetke et al. |
| 2007/0135885 | A1 | 6/2007 | Risi |
| 2008/0132970 | A1 | 6/2008 | Barolat |
| 2008/0208283 | A1 | 8/2008 | Vetter et al. |
| 2008/0255439 | A1 | 10/2008 | Tang et al. |
| 2008/0262584 | A1 | 10/2008 | Bottomley et al. |
| 2009/0099555 | A1 | 4/2009 | Viohl et al. |
| 2009/0102068 | A1 | 4/2009 | Pellinen et al. |
| 2009/0118806 | A1 | 5/2009 | Vetter et al. |
| 2009/0132042 | A1 | 5/2009 | Hetke et al. |
| 2009/0149934 | A1 | 6/2009 | Ameri et al. |
| 2009/0171421 | A1 | 7/2009 | Atalar et al. |
| 2009/0187196 | A1 | 7/2009 | Vetter |
| 2009/0240314 | A1 | 9/2009 | Kong et al. |
| 2009/0248118 | A1 | 10/2009 | Bradley et al. |
| 2009/0253977 | A1 | 10/2009 | Kipke et al. |
| 2009/0299167 | A1 | 12/2009 | Seymour |
| 2009/0312770 | A1 | 12/2009 | Kozai et al. |
| 2010/0030298 | A1 | 2/2010 | Martens et al. |
| 2010/0145216 | A1 | 6/2010 | He et al. |
| 2010/0145422 | A1 | 6/2010 | Seymour et al. |
| 2011/0093052 | A1 | 4/2011 | Anderson et al. |
| 2011/0154655 | A1 | 6/2011 | Hetke et al. |
- FOREIGN PATENT DOCUMENTS
- | | | |
|----|------------|---------|
| WO | 0241666 | 5/2002 |
| WO | 02096482 | 12/2002 |
| WO | 2005039696 | 5/2005 |
| WO | 2006138358 | 12/2006 |
| WO | 2007042999 | 4/2007 |
| WO | 2007089738 | 8/2007 |
| WO | 2008011721 | 1/2008 |
| WO | 2008038208 | 4/2008 |
| WO | 2008072125 | 6/2008 |
| WO | 2008109298 | 9/2008 |
| WO | 2009052423 | 4/2009 |
| WO | 2009052425 | 4/2009 |
| WO | 2010057095 | 5/2010 |
| WO | 2011010257 | 1/2011 |
| WO | 2011046665 | 4/2011 |
- OTHER PUBLICATIONS
- Application No. PCT/1B10/53250, International Search Report mailed Oct. 4, 2010.
- Application No. PCT/US04/35030, International Search Report mailed Feb. 21, 2005.
- Application No. PCT/US06/23139, International Search Report mailed Aug. 2, 2007.
- Application No. PCT/US07/02465, International Search Report mailed Feb. 13, 2008.
- Application No. PCT/US08/55025, International Search Report mailed Oct. 27, 2008.

(56)

References Cited

OTHER PUBLICATIONS

Application No. PCT/US08/80364, International Search Report and Written Opinion mailed Dec. 16, 2008.

Application No. PCT/US08/80366, International Search Report and Written Opinion mailed Dec. 10, 2008.

Application No. PCT/US09/64591, International Search Report and Written Opinion mailed Jul. 21, 2010.

Application No. PCT/US10/44167, International Search Report and Written Opinion mailed Sep. 27, 2010.

Kaplan et al., "A Novel Fabrication Method of Capillary Tubes on Quartz for Chemical Analysis Applications," IEEE Proc., Micro Electro Mech Systems, Jan. 25-28, 1994.

Lin et al., "Silicon Processed Microneedles," IEEE J. Micro. Electro. Mech. Syst, vol. 8, No. 1 (1999) 78-84 (7 pages).

Seymour et al. "Neural probe design for reduced tissue encapsulation in CNS," Biomaterials 28 (2007) 3594-3607, Apr. 5, 2007 (14 pages).

Seymour et al. "The insulation performance of reactive parylene films in electronic devices," Biomaterials (2009) 6158-6167, Aug. 22, 2009 (10 pages).

* cited by examiner

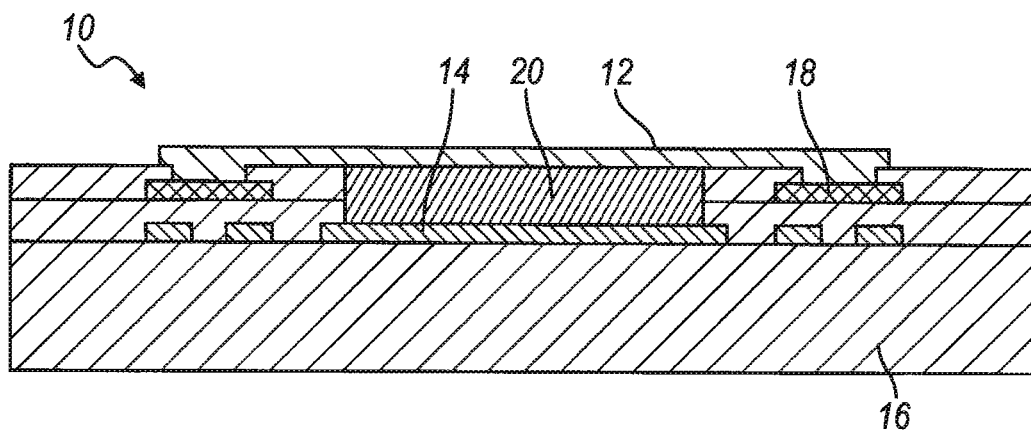


FIG. 1

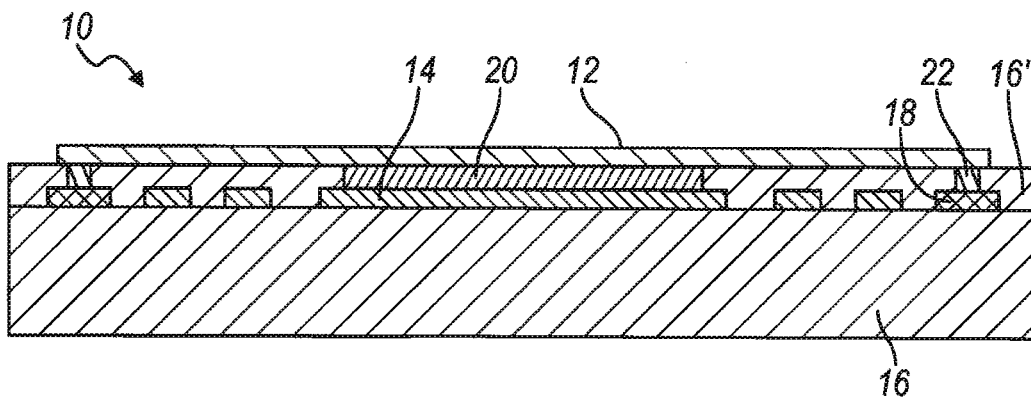


FIG. 2

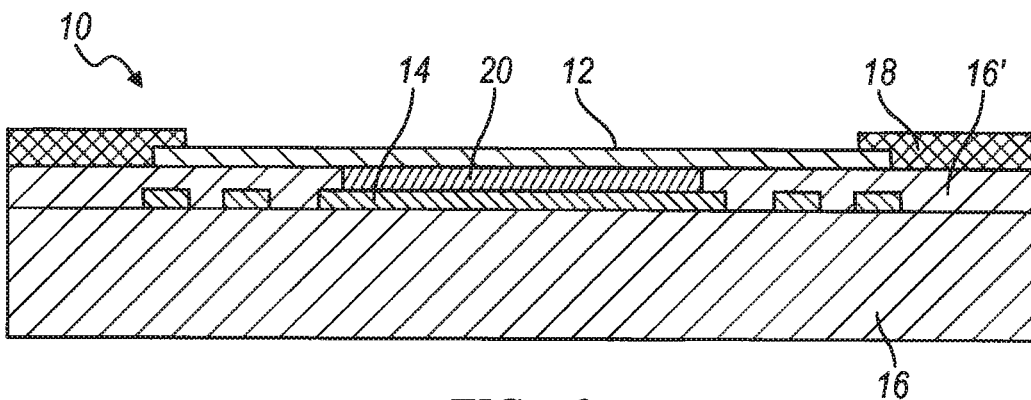


FIG. 3

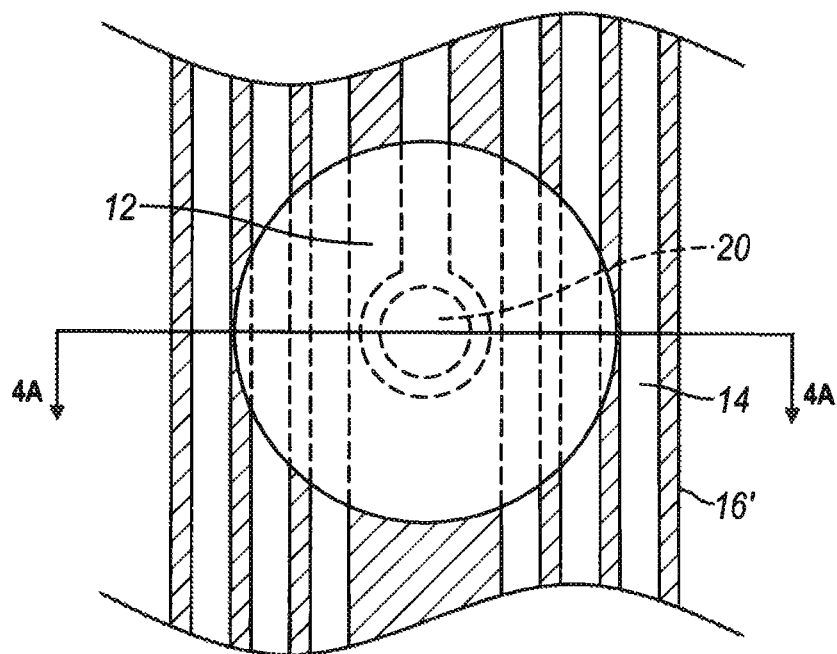


FIG. 4

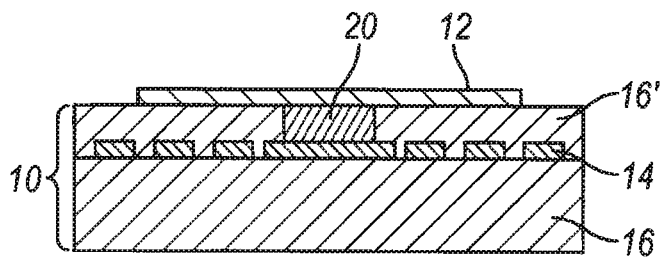


FIG. 4A

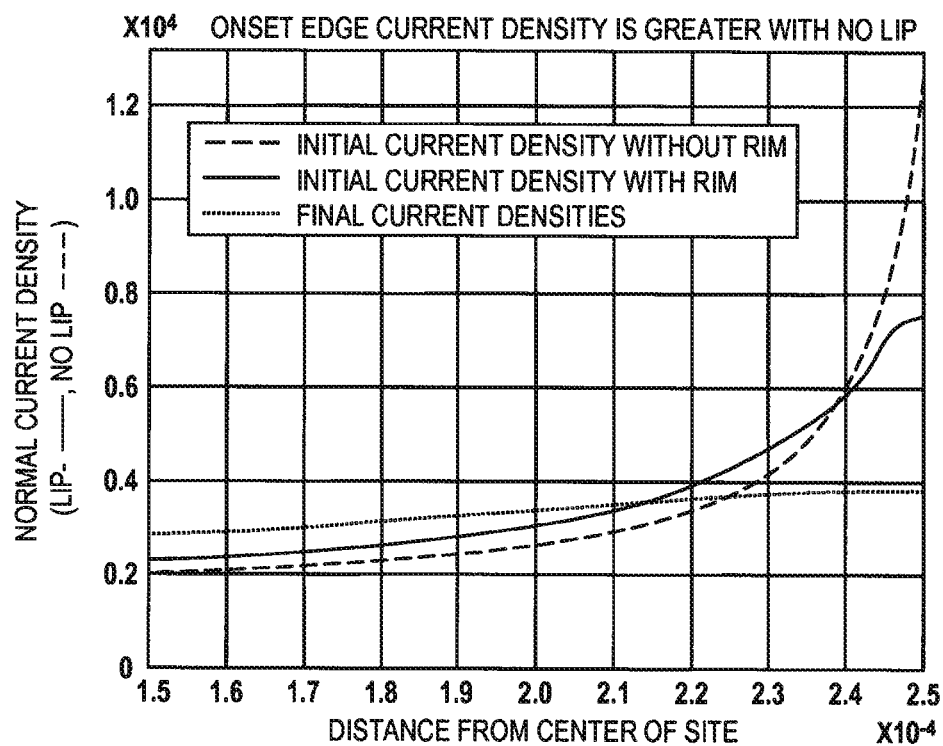


FIG. 5A

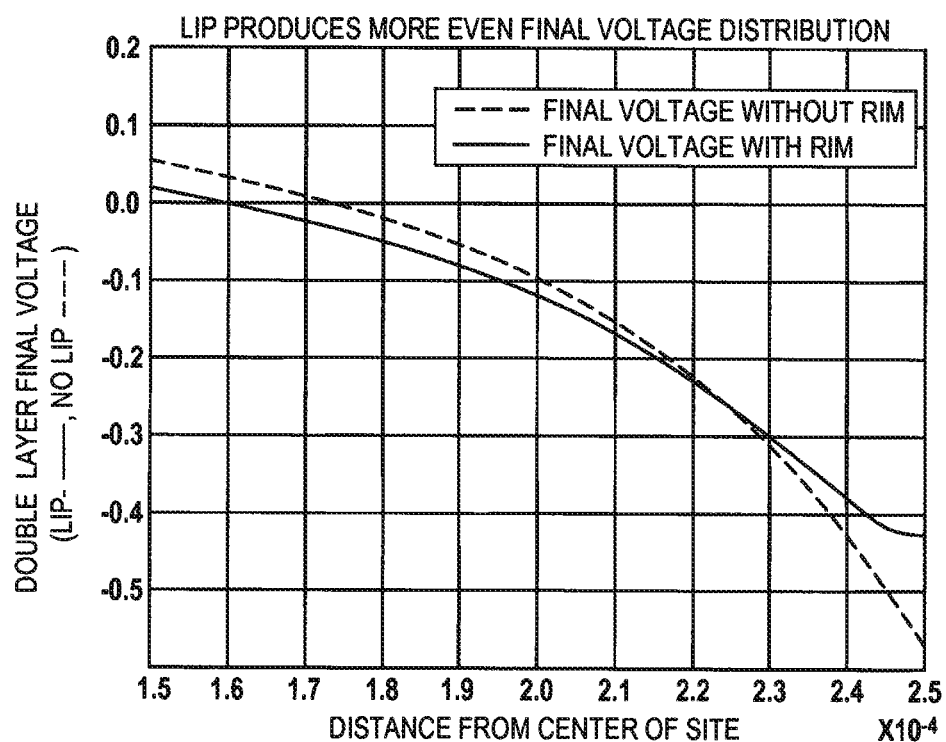


FIG. 5B

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IMPLANTABLE ELECTRODE AND METHOD OF MAKING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a divisional of U.S. patent application Ser. No. 12/396,107, filed on Mar. 2, 2009, which claims the benefit of U.S. Provisional Application. No. 61/032,725, filed on 29 Feb. 2008, which is incorporated in its entirety by this reference.

TECHNICAL FIELD

This invention relates generally to the implantable electrodes field, and more specifically to an improved implantable electrode with an anchoring element and the method of making this improved system.

BACKGROUND

The adhesion of metals to polymers in conventional micro-fabrication techniques can be quite poor. Excellent adhesion, however, is critical for biomedical electrodes, which are implanted in tissue and are exposed to harsh environments. In such environments, poorly connected elements can lead to irreversible chemical reactions and possible device failure. The irreversible chemical reactions can include: 1) electrolysis of water, with consequent pH changes and gas formation, 2) electrode dissolution due to oxide formation of soluble metal complexes, and 3) corrosion or breakdown of passivity. In conventional electrodes, uneven charging across the electrode site is often seen. As an example, a much higher current density is typically seen in the perimeter of the electrode site than seen in the center, thus when the electrode is placed onto the tissue of the patient, the uneven charging may lead to unpredictable stimulation of the tissue of the patient. Uneven charging across the electrode site also leads to additional irreversible chemical reactions. In the case of higher current density along the perimeter than seen in the center, a relatively high potential difference between the perimeter of the electrode and the center of the electrode develops, leading to a higher chance of irreversible chemical reactions at the edge of the electrode site. This invention provides an improved and useful system and method for connecting layers within an electrode, increasing the reliability of an electrode, and decreasing the chance of irreversible chemical reactions within an electrode.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 is a cross-sectional view of the implantable electrode of the preferred embodiment including a first variation of the anchoring element.

FIG. 2 is a cross-sectional view of the implantable electrode of the preferred embodiment including a second variation of the anchoring element.

FIG. 3 is a cross-sectional view of the implantable electrode of the preferred embodiment including a third variation of the anchoring element.

FIG. 4 is a top view and cross-sectional view of an implantable electrode.

FIG. 4A is a cross-sectional view along line 4A-4A of FIG. 4.

FIG. 5A is a graphical representation of the effect on current density across the electrode site of the preferred embodiment with the third variation of the anchoring element.

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FIG. 5B is a graphical representation of the double layer final voltage across the electrode site of the preferred embodiment with the third variation of the anchoring element.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description of preferred embodiments of the invention is not intended to limit the invention to these embodiments, but rather to enable any person skilled in the art to make and use this invention.

As shown in FIG. 1, the implantable electrode 10 of the preferred embodiments includes an electrode site 12, an interconnect 14 coupled to the electrode site 12, an insulating element 16 that functions to insulate the interconnect 14, and an anchoring element 18 that functions to anchor the electrode site 12 to the implantable electrode 10. The implantable electrode 10 of the preferred embodiment is preferably designed for an implantable electrode lead system to interface with brain tissue, the implantable electrode 10 of the preferred embodiments, however, may be alternatively used in any suitable environment (such as the spinal cord, peripheral nerve, muscle, or any other suitable anatomical location) and for any suitable reason.

1. The Implantable Electrode

As shown in FIGS. 1, 4 and 4A, the electrode site 12 of the preferred embodiment functions to record, stimulate, perform any other suitable function, or any combination thereof. The implantable electrode preferably includes a plurality of electrode sites 12, which may be independently tuned to record, stimulate, perform any other suitable function, or any combination thereof. Two or more electrode sites 12 may be grouped to form a larger composite site that enables tuning the neural interface region for recording and/or stimulation. The electrode site 12 is preferably a thin film metal, preferably made from gold, iridium, or platinum, but may alternatively be made from any suitable material.

The implantable electrode 10 of the preferred embodiments may further include a bond pad, which is electrically coupled to the electrode site 12 and functions to provide a point of contact to an external connector and/or device to provide a site from which recorded signals are accessed and/or to which stimuli are applied. The implantable electrode preferably includes a plurality of bond pads. The ratio of electrode sites 12 to bond pads is preferably 1:1, but may be any other suitable ratio. The bond pads are preferably gold, but may alternatively be any suitable material.

The implantable electrode 10 of the preferred embodiments may further include a plug 20 (also known as "leg"), which couples the electrode site 12 to the interconnect 14 and functions to transfer signals between the electrode site 12 and the interconnect 14. The implantable electrode preferably includes a plurality of plugs 20. The ratio of electrode sites 12 to plugs 20 is preferably 1:1, but may be any other suitable ratio. The plug 20 is preferably gold or platinum, but may alternatively be any suitable material.

As shown in FIGS. 1, 4 and 4A, the interconnect 14 of the preferred embodiment is coupled to the electrode site and functions to electrically couple the electrode site 12 to a bond pad or directly to an external connector and/or device and to transfer signals between the electrode site 12 and the bond pads, connector, and/or device. The implantable electrode preferably includes a plurality of interconnects 14. The ratio of electrode sites 12 to interconnects 14 is preferably 1:1, but may be any other suitable ratio. The interconnect 14 is preferably metal (such as platinum or gold) or polysilicon, but may alternatively be made out of any suitable material.

As shown in FIGS. 1, 4 and 4A, the insulating element 16 of the preferred embodiment functions to insulate the interconnect 14, preferably on the top and bottom side of the interconnect 14. The insulating element 16 is preferably one of several variations, and in some variations the insulating element 16 preferably includes multiple layers: a first layer 16 and a second layer 16'. In a first variation, where the interconnect 14 is preferably a metal such as platinum or gold, the insulating element 16 is preferably a polymer such as polyimide, parylene, or polydimethylsiloxane (PDMS). In a second variation, where the interconnect 14 is preferably polysilicon, the insulating element preferably includes a first layer 16 of inorganic dielectrics such as silicon dioxide or silicon nitride and a second layer 16' of a polymer. In a third variation, where the interconnect 14 is preferably polysilicon, the insulating element preferably includes a first layer 16 of inorganic dielectrics such as silicon dioxide or silicon nitride that are supported by a silicon substrate. The first layer 16 of inorganic dielectrics are preferably a tri-layer stack of silicon dioxide, silicon nitride, and silicon dioxide. Alternatives to the first layer 16 include silicon carbide and other polymers such as polyimide or parylene. The second layer 16' may be the same as the first layer, or may alternatively be a vapor deposited polymer such as parylene, Polytetrafluoroethylene (PTFE), other fluoropolymers, silicone, or any other suitable material. The second layer 16' preferably provides additional electrical insulation to leads.

As shown in FIGS. 1-3, the anchoring element 18 of the preferred embodiment functions to anchor the electrode site 12 to the implantable electrode 10. The anchoring element is preferably one of several variations. In a first variation, as shown in FIG. 1, the anchoring element 18 is a layer of metal. This metal layer is preferably located above the interconnect 14 such that it will not short or interfere with the interconnect 14. The metal layer is preferably located on the top surface of the second layer 16' of the insulation element 16. The metal electrode site 12 will adhere to the metal anchoring element 18. The strong metal-to-metal adhesion of the electrode site 12 to the anchoring element 18 preferably complements the adhesion of the electrode site 12 to the implantable electrode 10 (i.e. the top polymer surface). The anchoring element 18 in this variation is preferably buried in and/or under an additional layer 16" (preferably a polymer) of the insulation element 16 with a portion of the anchoring element 18 exposed to contact the electrode site 12. The exposed portion of the anchoring element 18 of this variation is preferably patterned to have a ring geometry that coincides with a perimeter portion of the electrode site 12. Alternatively, the exposed portion of the anchoring element 18 may form a semi-ring, may have multiple points, or may have any other suitable geometry. The geometry of the exposed portion of the anchoring element 18 may be defined by the anchoring element 18 and/or the additional layer 16" of the insulation element 16 and the pattern in which the anchoring element 18 is exposed.

In a second variation, as shown in FIG. 2, the anchoring element 18 is also a layer of metal, but this layer of metal is preferably located at the level of the interconnects 14 and is preferably insulated by the insulation element layers 16 and 16'. The metal electrode site 12 will adhere to the metal anchoring element 18. The strong metal-to-metal adhesion of the electrode site 12 to the anchoring element 18 preferably complements the adhesion of the electrode site 12 to the implantable electrode 10 (i.e. the top polymer surface). The anchoring element 18 of this variation preferably does not require the additional layer 16" of the insulation element 16, but rather, is preferably buried in the second layer 16 with a portion of the anchoring element 18 exposed to contact the

electrode site 12. The anchoring element 18 of this variation is preferably patterned to have multiple points or "spots" that coincide with the perimeter portion of the electrode site 12, and are preferably positioned such that the multiple points will not cross over or connect adjacent interconnects 14. Alternatively, the exposed portion of the anchoring element 18 may form a semi-ring or may have any other suitable geometry. The anchoring element 18 of this variation may further include a plug 22, which couples the electrode site 12 to the anchoring element 18. The plug 22 is preferably gold or platinum, but may alternatively be any suitable material.

In a third variation, as shown in FIG. 3, the anchoring element 18 is a layer of an insulating material, such as a polymer, that functions to mechanically couple the electrode site 12 to the implantable electrode 10. The mechanical coupling of the electrode site 12 to the anchoring element 18 preferably complements the adhesion of the electrode site 12 to the implantable electrode 10 (i.e. the top polymer surface). The anchoring element 18 is preferably an additional layer of the insulation element 16. The anchoring element 18 is preferably located on the top surface of the second layer 16' of the insulation element 16. The electrode site 12 in this variation is preferably buried in and/or under the anchoring element 18 with a portion of the electrode site exposed. The exposed portion will record, stimulate, perform any other suitable function, or any combination thereof. The anchoring element 18 is preferably patterned to form a lip or a rim around the perimeter portion of the electrode site 12. Alternatively, the anchoring element 18 may have any other suitable geometry.

As shown in FIGS. 5A and 5B, the third variation of the anchoring element 18 also functions to normalize (or "make more uniform") the initial current distribution along the electrode site 12. In conventional implantable electrodes, as a stimulation pulse is sent to the electrode site 12, the initial, current density along the electrode site 12 is not uniform. The current density along the perimeter of the electrode site 12 is higher than that at the center of the electrode site 12, leading to uneven changing across the electrode site 12 and creating a potential difference between the perimeter and the center of the electrode site 12. The difference in potential may lead to unpredictable stimulation of the tissue of the patient, such as charge spikes along the electrode site 12, and an increased chance of irreversible chemical reactions at the perimeter of the electrode site 12, thereby potentially releasing toxic products into the tissue of the patient and decreasing the effectiveness of the electrode 10. The third variation of the anchoring element 18 provides a raised lip along the perimeter of the electrode site 12. This raised lip has been shown to decrease the difference in initial current densities along the electrode site 12, as shown in FIG. 5A, leading to a more normalized final voltage potential distribution along the electrode site 12, as shown in FIG. 5B, increasing the reliability of the electrode and decreasing the chance of irreversible chemical reactions.

The anchoring element 18 of the third variation may alternatively be shaped to accommodate to the type of charge distribution desired across the electrode site 12. For example, a higher charge distribution may be desired in a first region than in a second region of the electrode site 12. To achieve this, the raised lip may be thicker in the second region than in the first region. Alternatively, the raised lip of the anchoring element 18 may be of a uniform thickness around the perimeter of the electrode site 12 to achieve higher mitigation of the current density at the perimeter. However, any other arrangement of the anchoring element 18 suitable to regulate the charge distribution across the electrode site 12 may be used.

The anchoring element 18 of the third variation may also be shaped to accommodate to the type of mechanical interlock

desired across the electrode site **12**. For example, the raised lip of the anchoring element **18** may be shaped as an “X” across the electrode site **12**, but may alternatively also be shaped as parallel ridges across the electrode site **12**. However, any other arrangement of the anchoring element **18** suitable to provide an adequate mechanical interlock across the electrode site **12** may be used.

2. Method of Making the Implantable Electrode

The implantable electrode **10** of the preferred embodiment is preferably micro-machined using standard microfabrication techniques, but may alternatively be fabricated in any other suitable fashion. As shown in FIGS. **4** and **4A**, the method of building an implantable electrode of the preferred embodiment includes building a first layer of the insulating element **16** **S102**, building an interconnect **14** **S104**, building a second layer of the insulating element **S106**, removing a portion of the second layer **16'** to expose a portion of the interconnect **14** **S108**, building a layer of conductive material to fill the second layer **16'** **S110**, and building the electrode site **12** **S112**.

The method of building an implantable electrode with an anchoring element **18** of the preferred embodiments preferably includes additional and/or alternative steps to build the anchoring element **18** in one of several variations. In a first variation, as shown in FIG. **1**, after Step **S106** the method of the first variation includes building an anchoring element **18** **S114**, building a third layer **16''** of the insulating element **16** **S116**, removing a portion of the third layer **16''** to expose a portion of the anchoring element **18** and to expose a portion of the second layer **16'** above the interconnect **14** **S118**, removing a portion of the second layer **16'** to expose a portion of the interconnect **14** **S108**, building a layer of conductive material to fill the second layer **16'** and the portion of the third layer **16''** above the interconnect **14** **S110**, and building the electrode site **12** **S112**.

In a second variation, as shown in FIG. **2**, the method of the second variation includes an alternative Step **S104'**: building an interconnect **14** and an anchoring element **18**, and an alternative Step **S108'**: removing a portion of the second layer **16'** to expose a portion of the interconnect **14** and the anchoring element **18**. In a third variation, as shown in FIG. **3**, the method of the third variation includes two additional steps after Step **S112**. Those steps include building an anchoring element **18** **S120**, and removing a portion of the anchoring element **18** to expose a portion of the electrode site **12** **S122**. The method is preferably designed for the manufacture of implantable electrodes, and more specifically for the manufacture of implantable electrodes with anchoring elements. The method and any variation thereof, however, may be alternatively used in any suitable environment and for any suitable reason.

Step **S102**, which recites building a first layer of the insulating element **16**, functions to provide the base layer of the implantable electrode **10**. The adding of material is preferably performed through any suitable deposition process that grows, coats, or transfers a material in any other suitable method. These deposition processes may include spinning and curing, physical vapor deposition (PVD), chemical vapor deposition (CVD), electrochemical deposition (ECD), molecular beam epitaxy (MBE) and more recently, atomic layer deposition (ALD), or any other suitable process.

Step **S104** and **S104'**, which recite building an interconnect **14** and building an interconnect **14** and an anchoring element **18** respectively, function to create the interconnects and/or the metal anchoring elements **18**. This step is preferably performed by building a layer of material and then patterning the layer of material to form the interconnects **14** and/or the

anchoring elements **18**. The adding of material is preferably performed through any suitable deposition process that grows, coats, or transfers a material in any other suitable method. These deposition processes may include sputtering, evaporating, physical vapor deposition (PVD), chemical vapor deposition (CVD), electrochemical deposition (ECD), molecular beam epitaxy (MBE) and more recently, atomic layer deposition (ALD), or any other suitable process. The removal or patterning of material is preferably performed through reactive ion etching (RIE), but may alternatively be performed through any other suitable removal process, such as other dry etching methods, wet etching, chemical-mechanical planarization, or any combination thereof. The interconnects **14** and/or the anchoring elements **18** may alternatively be created by any suitable combination of deposition, removal, and or patterning.

Step **S106**, which recites building a second layer **16** of the insulating element is preferably performed in a similar fashion to Step **S102** above.

Step **S108**, **S108'**, and **S118**, which recite removing a portion of the insulating element to expose a portion of the interconnect **14**, the anchoring element **18**, and/or a lower layer of the insulating element function to expose a contact through the insulating element to the layer below. The removal or patterning of material is preferably performed through reactive ion etching (RIE), but may alternatively be performed through any other suitable removal process, such as other dry etching methods, wet etching, chemical-mechanical planarization, or any combination thereof. The interconnects **14** and/or the anchoring elements **18** may alternatively be created by any suitable combination of deposition, removal, and or patterning.

Step **S110** and **S110'**, which recite building a layer of conductive material to fill a layer of the insulating element, function to build a “plug” (also known as “leg”) to fill the contact hole with conductive material and to form the plugs **20** and/or **22**. The step is preferably performed through electroplating, but may alternatively be performed through any suitable deposition process that grows, coats, or transfers a material in any other suitable method.

Step **S112**, which recites building the electrode site **12**, functions to create electrode site **12**. This step is preferably performed by building a layer of material and then patterning the layer of material to form the electrode site **12**. This step preferably uses a method to add material and then remove material as described in Step **S104**.

Step **S114**, which recites building an anchoring element **18**, functions to create the metal layer anchoring element **18** of the first variation. This step is preferably performed by building a layer of material and then patterning the layer of material to form the anchoring element **18**. This step preferably uses a method to add material and then remove material as described in Step **S104**.

Step **S116** and Step **S120**, which recite building an anchoring element **18** and building a third layer **16''** of the insulating element **16**, function to create the anchoring element **18** of the third variation (which is preferably an insulating material) and to build the third layer of the insulating element, respectively. This is preferably performed in a similar fashion as described in Step **S102**.

Step **S122**, which recites removing a portion of the anchoring element **18** to expose a portion of the electrode site **12**, functions to expose a contact through the anchoring element **18** to the electrode site **12**. The removal or patterning of material is preferably performed through a deep reactive ion etching (DRIE), but may alternatively be performed through any other suitable removal process, such as other dry etching

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methods, wet etching, chemical-mechanical planarization, or any combination thereof. The interconnects **14** and/or the anchoring elements **18** may alternatively be created by any suitable combination of deposition, removal, and or patterning.

Although omitted for conciseness, the preferred embodiments include every combination and permutation of the various implantable electrodes, the various interconnects, the various insulation elements, the various anchoring elements, and the various methods of making the various implantable electrodes.

As a person skilled in the art will recognize from the previous detailed description and from the figures and claim, modifications and changes can be made to the preferred embodiments of the invention without departing from the scope of this invention defined in the following claim.

What is claimed is:

1. An implantable electrode, comprising:
 - a) an insulator layer;
 - b) an electrically conductive interconnect layer supported by a first portion of the insulator layer, the interconnect layer comprising an interconnect width extending between spaced apart first and second interconnect edges;
 - c) an electrically conductive plug layer supported directly on an upper interconnect surface of the interconnect layer, the plug layer comprising a plug width extending between spaced apart first and second plug edges;
 - d) an electrically conductive electrode layer supported directly on an upper plug surface of the plug layer, the electrode layer comprising an electrode width or diameter extending between spaced apart first and second electrode edges;
 - e) an anchor layer supported by the first portion of the insulator layer and being physically and electrically connected to the electrode layer adjacent to at least one of the first and second electrode edges, wherein the anchor layer comprises at least two anchor portions spaced from the interconnect layer, each anchor portion having an anchor width extending between spaced apart first and second anchor edges;
 - f) a second portion of the insulator layer supported on the first portion of the insulator layer and contacting the plug,
 - g) wherein the second portion of the insulator layer is in an overlaying relationship with the upper interconnect surface and with the upper anchor surface to thereby lock the interconnect and anchor layers between the first and second portions of the insulator layer.
2. The implantable electrode of claim **1** wherein the anchor layer has an outer peripheral shape that is substantially similar to an outer peripheral shape of the electrode layer.
3. The implantable electrode of claim **1** wherein the anchor layer has a ring shape.
4. The implantable electrode of claim **1** wherein the at least two portions of the anchor layer are contiguous.
5. The implantable electrode of claim **1** wherein the interconnect layer is of platinum or gold and the first and second portions of the insulator layer are a polymer selected from the group consisting of polyimide, parylene, and polydimethylsiloxane (PDMS).
6. The implantable electrode of claim **1** wherein the interconnect layer is polysilicon, the first portion of the insulator layer is an inorganic dielectric selected from silicon dioxide and silicon nitride, and the second portion of the insulator layer is a polymer selected from the group consisting of polyimide, parylene, and polydimethylsiloxane (PDMS).

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7. The implantable electrode of claim **1** wherein the interconnect is polysilicon, and wherein the first portion of the insulator layer is selected from the group consisting of silicon carbide, polyimide, and parylene.

8. The implantable electrode of claim **1** wherein the interconnect layer contacts the electrode layer spaced inwardly from a peripheral edge of the electrode layer.

9. The implantable electrode of claim **1** wherein the electrode layer is a neural interface that provides at least one function selected from the group consisting of recording and stimulating.

10. The implantable electrode of claim **1** wherein the anchor layer is chemically bonded to the first portion of the insulator layer.

11. The implantable electrode of claim **1** wherein the electrode layer is supported on an upper surface of the second portion of the insulator layer.

12. The implantable electrode of claim **1** wherein both the electrode layer and the anchor layer are of a metal material.

13. The implantable electrode of claim **1** wherein the second portion of the insulator layer partially envelops the anchor layer and defines an opening to expose a portion of the anchor layer, thereby mechanically interlocking the second portion of the insulator layer and the anchor layer.

14. The implantable electrode of claim **1** wherein the electrode layer is chemically bonded to the second plug layer.

15. The implantable electrode of claim **1** wherein both the insulator layer and the anchor layer are of a material that acts as an electrical insulator.

16. The implantable electrode of claim **1** wherein the first portion of the insulator layer supports the interconnect layer and the anchor layer, and wherein the second portion of the insulator layer contacts both the interconnect layer and the anchor layer and physically insulates the interconnect layer from the anchor layer.

17. The implantable electrode of claim **1** wherein the second portion of the insulator layer contacts the first plug edge, and wherein the second portion of the insulator layer extending to the overlaying relationship with the upper anchor surface also contacts the first edge of the interconnect layer.

18. An implantable electrode system, comprising:

- a) a first insulator layer;
- b) an electrically conductive interconnect layer supported on an upper surface of the first insulator layer, the interconnect layer comprising an interconnect width extending between spaced apart first and second interconnect edges;
- c) an electrically conductive plug layer supported directly on an upper interconnect surface of the interconnect layer, the plug layer comprising a plug width extending between spaced apart first and second plug edges;
- d) an electrically conductive electrode layer supported directly on an upper plug surface of the plug layer, the electrode layer comprising an electrode width or diameter extending between spaced apart first and second electrode edges;
- e) an anchor layer supported on the upper surface of the first insulator layer and being physically and electrically connected to the electrode layer adjacent to at least one of the first and second electrode edges, wherein the anchor layer comprises at least two anchor portions spaced from the interconnect layer, each anchor portion having an anchor width extending between spaced apart first and second anchor edges; and
- f) a second insulator layer supported on the first insulator layer, wherein a portion of the second insulator layer resides between the first and second plug edges and

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extends to an overlaying relationship with a portion of an upper anchor surface of the anchor layer to thereby lock the anchor layer between the first and second insulator layers.

19. The implantable electrode of claim 18 wherein the anchor is of an electrically conductive material or is an electrical insulator.

20. An implantable electrode, comprising:

- a) a first insulator layer;
- b) an electrically conductive interconnect layer supported on an upper surface of the first insulator layer, the interconnect layer comprising an interconnect width extending between spaced apart first and second interconnect edges;
- c) an electrically conductive plug layer supported directly on an upper interconnect surface of the interconnect layer, the plug layer comprising a plug width extending between spaced apart first and second plug edges;
- d) an electrically conductive electrode layer supported directly on an upper plug surface of the plug layer, the electrode layer comprising an electrode width or diameter extending between spaced apart first and second electrode edges;
- e) an anchor layer supported on the upper surface of the first insulator layer and being physically and electrically connected to the electrode layer adjacent to at least one of the first and second electrode edges, wherein the anchor layer comprises at least two anchor portions spaced from the interconnect layer, each anchor portion having an anchor width extending between spaced apart first and second anchor edges; and
- f) a second insulator layer supported on the first insulator layer, wherein a portion of the second insulator layer contacts the first and second plug edges and extends to an overlaying relationship with a portion of an upper anchor surface of the anchor layer to thereby lock the anchor layer between the first and second insulator layers.

21. The implantable electrode of claim 20 wherein the anchor is of an electrically conductive material or is an electrical insulator.

22. An implantable electrode, comprising:

- a) a first insulator layer;
- b) an electrically conductive interconnect layer supported on an upper surface of the first insulator layer, the interconnect layer comprising an interconnect width extending between spaced apart first and second interconnect edges;
- c) an electrically conductive plug layer supported directly on an upper interconnect surface of the interconnect layer, the plug layer comprising a plug width extending between spaced apart first and second plug edges, wherein the plug width is less than the interconnect width;
- d) an electrically conductive electrode layer supported directly on an upper plug surface of the plug layer, the electrode layer comprising an electrode width or diameter extending between spaced apart first and second electrode edges, wherein the electrode width is greater than both the interconnect width and the plug width;
- e) an anchor layer supported on the upper surface of the first insulator layer and being physically and electrically connected to the electrode layer adjacent to at least one of the first and second electrode edges, wherein the anchor layer comprises at least two anchor portions spaced from the interconnect layer, each anchor portion

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having an anchor width extending between spaced apart first and second anchor edges; and

- f) a second insulator layer supported on the first insulator layer and contacting the first and second plug edges,
- g) wherein the second insulator layer is in an overlaying relationship with both the upper interconnect surface and the upper anchor surface to thereby lock the interconnect and anchor layers between the first and second insulator layers.

23. The implantable electrode of claim 22 wherein the anchor is of an electrically conductive material or is an electrical insulator.

24. An implantable electrode system, comprising:

- a) an insulator layer;
- b) an electrically conductive interconnect layer supported on an upper surface of the first insulator layer, the interconnect layer comprising an interconnect width extending between spaced apart first and second interconnect edges;
- c) an electrically conductive plug layer supported directly on an upper interconnect surface of the interconnect layer, the plug layer comprising a plug width extending between spaced apart first and second plug edges, wherein the plug width is less than the interconnect width;
- d) an electrically conductive electrode layer supported directly on an upper plug surface of the plug layer, the electrode layer comprising an electrode width or diameter extending between spaced apart first and second electrode edges; wherein the electrode width is greater than both the interconnect width and the first plug width;
- e) an anchor layer supported on the upper surface of the first insulator layer and being physically and electrically connected to the electrode layer adjacent to at least one of the first and second electrode edges, wherein the anchor layer comprises at least two anchor portions spaced from the interconnect layer, each anchor portion having an anchor width extending between spaced apart first and second anchor edges; and
- f) a second insulator layer supported on the first insulator layer and contacting the first and second plug edges,
- g) wherein a portion of the second insulator layer extends to an overlaying relationship with both the upper interconnect surface and the upper anchor surface to thereby lock the interconnect and anchor layers between the first and second insulator layers.

25. The implantable electrode of claim 24 wherein the anchor is of an electrically conductive material or is an electrical insulator.

26. An implantable electrode, comprising:

- a) an insulator layer;
- b) an electrically conductive interconnect layer supported on an upper surface of the first insulator layer, the interconnect layer comprising an interconnect width extending between spaced apart first and second interconnect edges;
- c) an electrically conductive plug layer supported directly on an upper interconnect surface of the interconnect layer, the plug layer comprising a plug width extending between spaced apart first and second plug edges, wherein the plug width is less than the interconnect width;
- d) an electrically conductive electrode layer supported directly on an upper plug surface of the plug layer, the electrode layer comprising an electrode width or diameter extending between spaced apart first and second

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- electrode edges; wherein the electrode width is greater than both the interconnect width and the first plug width;
- e) an anchor layer supported on the upper surface of the first insulator layer and being physically and electrically connected to the electrode layer adjacent to at least one of the first and second electrode edges, wherein the anchor layer comprises at least two anchor portions spaced from the interconnect layer, each anchor portion having an anchor width extending between spaced apart first and second anchor edges; and
 - f) a second insulator layer supported on the first insulator layer and contacting the plug layer,
 - h) wherein a portion of the second insulator extends to an overlaying relationship with both the upper interconnect surface and the upper anchor surface to thereby lock the interconnect and anchor layers between the first and second insulator layers.
27. The implantable electrode of claim 26 wherein the anchor is of an electrically conductive material or is an electrical insulator.
28. An implantable electrode, comprising:
- a) an insulator layer;
 - b) an electrically conductive interconnect layer supported on an upper surface of the first insulator layer, the interconnect layer comprising an interconnect width extending between spaced apart first and second interconnect edges;
 - c) an electrically conductive plug layer supported directly on an upper interconnect surface of the interconnect layer, the first plug layer comprising a first plug width extending between spaced apart first and second first plug edges,

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- d) an electrically conductive electrode layer supported directly on an upper first plug surface of the first plug layer, the electrode layer comprising an electrode width or diameter extending between spaced apart first and second electrode edges;
 - e) an anchor layer supported on the upper surface of the first insulator layer, wherein the anchor layer comprises at least two anchor portions spaced from the interconnect layer, each anchor portion having an anchor width extending between spaced apart first and second anchor edges;
 - f) an electrically conductive second plug layer supported on the anchor layer and being physically and electrically connected to the electrode layer adjacent to at least one of the first and second electrode edges, wherein the second plug layer comprises a second plug width extending between spaced apart first and second edges; and
 - g) a second insulator layer supported on the first insulator layer and contacting the first and second first plug edges and the first and second edges of the second plug,
 - h) wherein the second insulator layer is in an overlaying relationship with both the upper interconnect surface and with the upper anchor surface to thereby lock the interconnect and anchor layers between the first and second insulator layers.
29. The implantable electrode of claim 28 wherein the anchor is of an electrically conductive material or is an electrical insulator.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 9,265,928 B2
APPLICATION NO. : 13/713115
DATED : February 23, 2016
INVENTOR(S) : David S. Pellinen et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:


In the claims

Column 10, line 14 delete “an” and insert --a first--

Column 10, line 52 delete “an” and insert --a first--

Column 11, line 22 delete “an” and insert --a first--

Signed and Sealed this
Seventeenth Day of May, 2016

A handwritten signature in black ink, reading "Michelle K. Lee". The signature is fluid and cursive, with the first letters of each name being capitalized and prominent.

Michelle K. Lee
Director of the United States Patent and Trademark Office